

# Feasibility of Recycling Hohlraum Wall Materials

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ARIES Meeting  
April 22 - 23, 2002  
UW



# Objectives

- Address feasibility of recycling candidate hohlraum wall materials:

	Mass (tons/FPY)	Cost* (M\$/FPY)	Resources Problem?
<b>Au/Gd</b> (reference)	15	80	yes, Gd
<b>Au</b>	21	210	
<b>W</b>	21		
<b>Pb</b>	12		
<b>Hg</b>	15		
<b>Ta</b>	18	0.6	
<b>Pb/Ta/Cs</b>	10		
<b>Hg/W/Cs</b>	11		
<b>Pb/Hf</b>	13		
<b>Hf</b>	14	2.6	
<b>Solid Kr @ 115.8 k</b>	3	?	?
<b>Solid Xe @ 161.1 k</b>	4	?	?

\* 10\$/g-Au. 0.015 \$/g-Gd, 0.187 \$/g-Hf, 0.034 \$/g-Ta, per Waganer (Boeing)



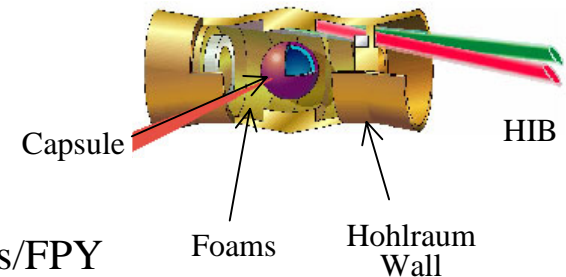
# Objectives (cont.)

- Lacking info on economic/resources problem, **develop recycling approach for all hohlraum wall materials using ARIES design criteria and requirements**
- **Analyze two extreme cases:**
  - One-shot use of hohlraum wall materials then dispose in repositories
  - Recycle without transmutation removal system
- **Recommend design solutions** for materials exhibiting recycling problems
- Investigate means for **dealing with large quantity of radioactive gases @ EOL**



# HIB Target Parameters

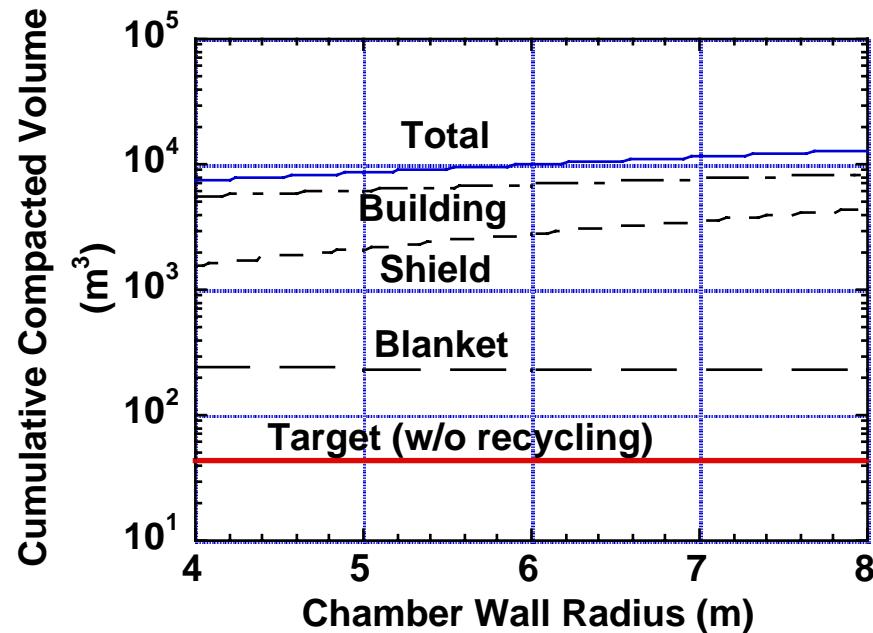
Capsule Radius*	2.34 mm
Hohlraum Wall Thickness*	15 $\mu\text{m}$
Target yield	458.7 MJ
Rep Rate	4 Hz
# of Shots	126 million shots/FPY
Plant Lifetime	40 FPY (47 y)
Availability	85%
<b>Volume</b> of Hohlraum Wall	0.0085 $\text{cm}^3/\text{target}$ 1.1 $\text{m}^3/\text{FPY}$ <b>43 <math>\text{m}^3/40 \text{ FPY}</math></b>
<b>Mass</b> of Hohlraum Materials	3-21 tons/FPY <b>120-830 tons/40 FPY</b>



**LLNL Close-Coupled  
Target Design**

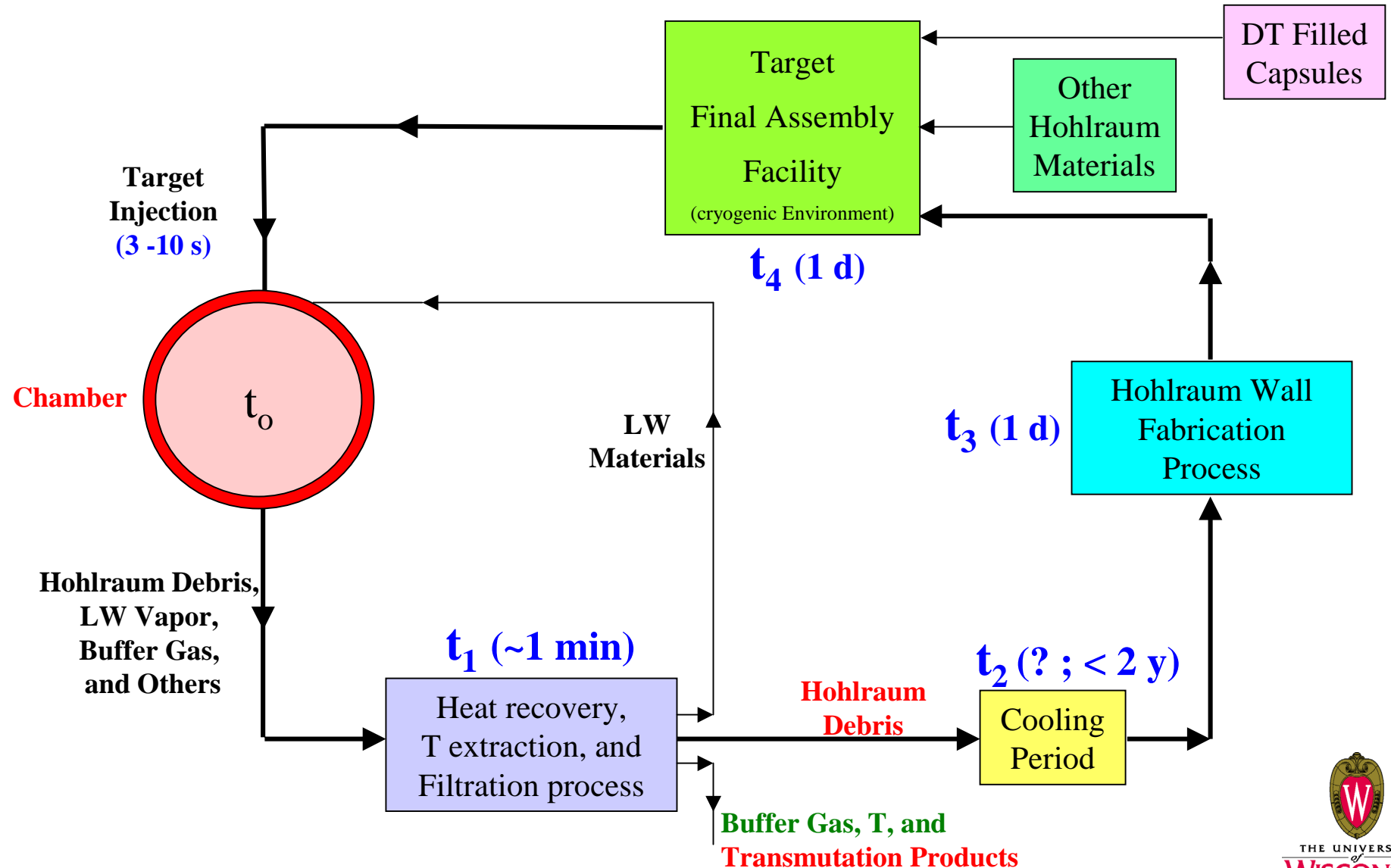
\* D. Callahan-Miller and M. Tabak, Phys of Plasmas, Vol 7, p 2083, May 2000

# Hohlraum Wall Materials Represent < 1% of IFE Waste Stream



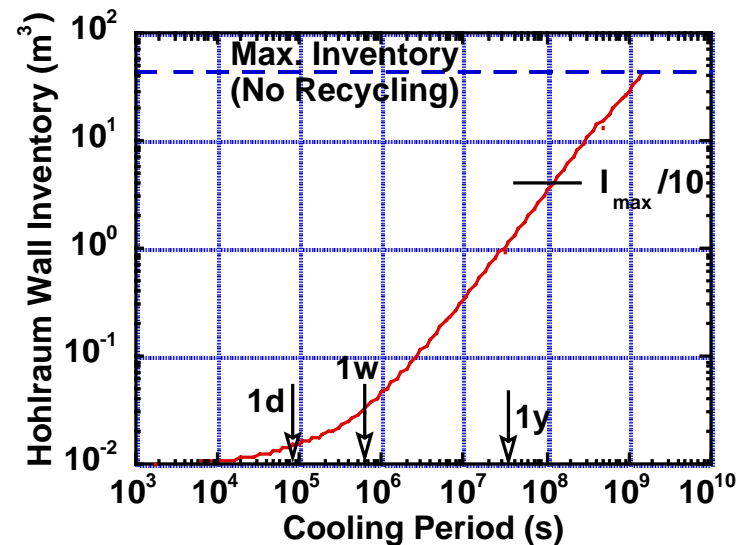
**Recycle costly/rare materials to reduce inventory by factor of 10 or more**

# Hohlraum Wall Recycling Process



# Cooling Periods $\leq 2$ y Reduce Hohraum Inventory by Factor of 10 or more

- Inventory varies linearly with cooling period
- Steady-state inventory accounts for:
  - 2 d back-up
  - $t_2+1$  d
  - 2 d for recycling
  - Short time in chamber
- 2 d backup inventory is needed to account for repair of recycling system; e.g.,  $0.006 \text{ m}^3$  (80 kg of Au/Gd)
- Store irradiated materials in 1h or 1d bins, depending on cooling period unit
- Start-up inventory !?
- More sophisticated approach could reduce inventory further



# Recycling Introduces Problems

- Produces high level waste (**HLW**) for most materials
  - Increases **activity and decay heat**
  - Mandates **remote handling** (costly) in target fab
  - Requires **radioactive storage** system
- ⇒ **Adds cost and complexity** to target assembly/fabrication facility





# Several Factors May Prematurely Terminate Recycling Process Requiring Fresh Hohraum Wall Materials

- **Waste disposal rating\*** of hohlraum debris violates Class C low level waste requirement
- **Recycling dose\*** exceeds hands-on or remote handling limits
- **Accident dose** at site boundary exceeds 1 rem following accidents in chamber and/or in Target Fab
- **Transmutation level** in hohlraum debris reaches limit set by target designers to minimize beam losses to hohlraum walls. **Alternative option** is to separate transmutations on-line and address feasibility and economic issues
- **Decay heat** of radioactive hohlraum materials raises frozen DT temp above 1.8 K before target injection. Mogahed's preliminary analysis showed insignificant change in temperature for LLNL target design meaning foams provide good thermal shield for capsule

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\* Most restrictive factors in descending order

# Potential Design Solutions for Materials with Recycling Problems

- I- Filter out **transmutations** on-line  $\Rightarrow$
- Cup(s) of HLW
  - Lowest LLW inventory
  - Recycle for plant life (47 y)
  - No cooling period
- II- Limit **exposure time** (or end recycling process) and call for fresh materials  $\Rightarrow$
- No transmutations removal system (unpractical)
  - No HLW
  - Exclude Gd
  - Larger LLW inventory than Option-I
  - No cooling period
  - Recycle for < 47 y
- III- Store materials for < 2 y of **cooling period** before fabrication  $\Rightarrow$
- No transmutations removal system (unpractical)
  - No HLW
  - Exclude Gd
  - Lower LLW inventory than Option-II
  - Recycle for plant life (47 y)

Other simple solutions:

- Do not recycle
- Exclude material(s) from list

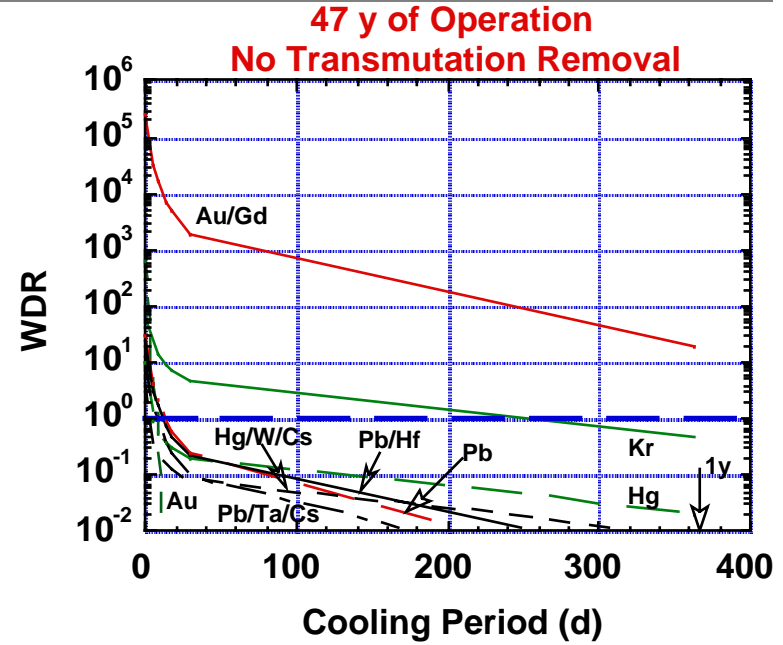
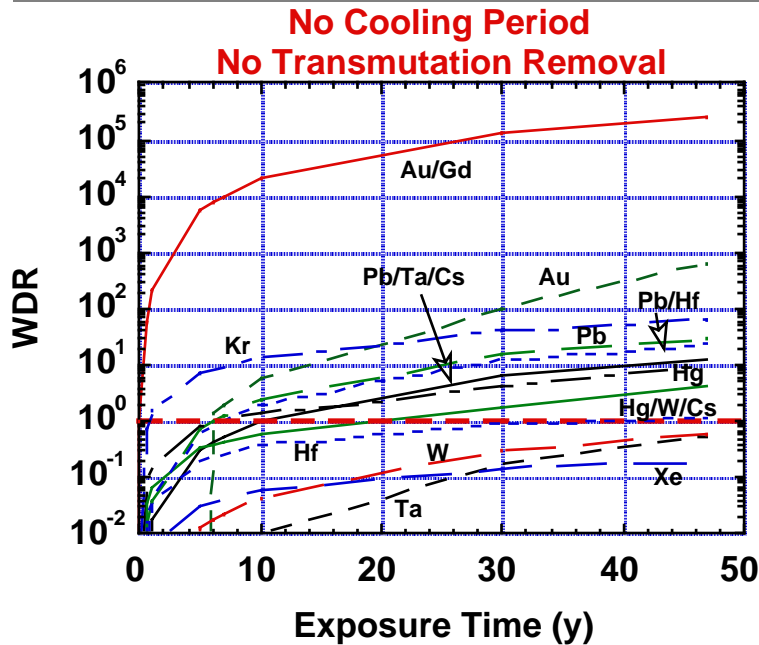
# No Major Change in Material's WDR after One Shot

<u>Hohlraum Wall Materials</u>	<u>WDR</u>	<u>EOL Inventory</u>	
		<u>m<sup>3</sup></u>	<u>Tons</u>
Gold/Gadolinium (ref.)	$2 \times 10^{-8}$	43	580
Gold	0	43	830
Tungsten	$2 \times 10^{-6}$	43	830
Lead	$2 \times 10^{-5}$	43	480
Mercury	$5 \times 10^{-4}$	43	580
Tantalum	0	43	710
Lead/Tantalum/Cesium	$1 \times 10^{-5}$	43	390
Mercury/Tungsten/Cesium	$2 \times 10^{-4}$	43	450
Lead/Hafnium	$8 \times 10^{-5}$	43	510
Hafnium	$3 \times 10^{-4}$	43	560
Solid Kr	<b>0.01</b>	43	120
Solid Xe	$2 \times 10^{-5}$	43	150

Without recycling, all materials qualify as **Class C** (or A) LLW after one shot



# Limit Exposure Time or Cooling Period to Control WDR



- WDR reported at 100 y after exposure using Fetter's limits, except for Xe (NRC)

- **Recommendations:**

- Gd generates HLW after 2.5 s (10 pulses)  $\Rightarrow$  Do not recycle Gd unless on-line highly efficient clean-up system removes all Tb
- W, Ta and Xe are Class C waste @ EOL even with no cooling period or clean-up system
- For other materials :
  - Limit exposure time to 0.7 - 35 years for no cooling period
  - Or, extend cooling period to 0.6 - 250 days and recycle for 47 y of operation



# Use of Cooling Period to Control WDR is Preferred to Lower EOL Inventory

	Maximum Exposure Time*	Total Inventory @ EOL (m <sup>3</sup> )
Au	5.9 y	0.1
W	47 y	0.01
Pb	6 y	0.1
Hg	6 y	0.1
Ta	47 y	0.01
Pb/Ta/Cs	9.5 y	0.06
Hg/W/Cs	19 y	0.04
Pb/Hf	6.4 y	0.09
Hf	35 y	0.02
Solid Kr	0.7 y	0.8
Solid Xe	47 y	0.01

\* No cooling period. No transmutation removal

	Minimum Cooling Period <sup>#</sup>	Total Inventory @ EOL (m <sup>3</sup> )
Au	8.2 d	0.03
W	0	0.01
Pb	13 d	0.06
Hg	5 d	0.03
Ta	0	0.01
Pb/Ta/Cs	7.5 d	0.04
Hg/W/Cs	3 d	0.02
Pb/Hf	11.5 d	0.06
Hf	0.6 d	0.02
Solid Kr	250 d	0.8
Solid Xe	0	0.01

<sup>#</sup> 47 y of operation. No transmutation removal

On-line removal of transmutation products prolongs exposure time and shortens cooling period further but generates cup(s) of HLW



# All Materials Must Meet Recycling Dose Limits

<b>Hands-on limit*#:</b>	
without ALARA principle	10 $\mu$ Sv/h
with ALARA principle	1 $\mu$ Sv/h
<b>Conservative Remote handling limit*##</b>	10 mSv/h
<b>Advanced Remote Handling Limit+</b> (recommended for ARIES)	<b>3000 Sv/h</b>

\* Ref: D. Petti et al., "Safety Analysis of Initiating Events", ARIES E-meeting, Oct 17, 2001.

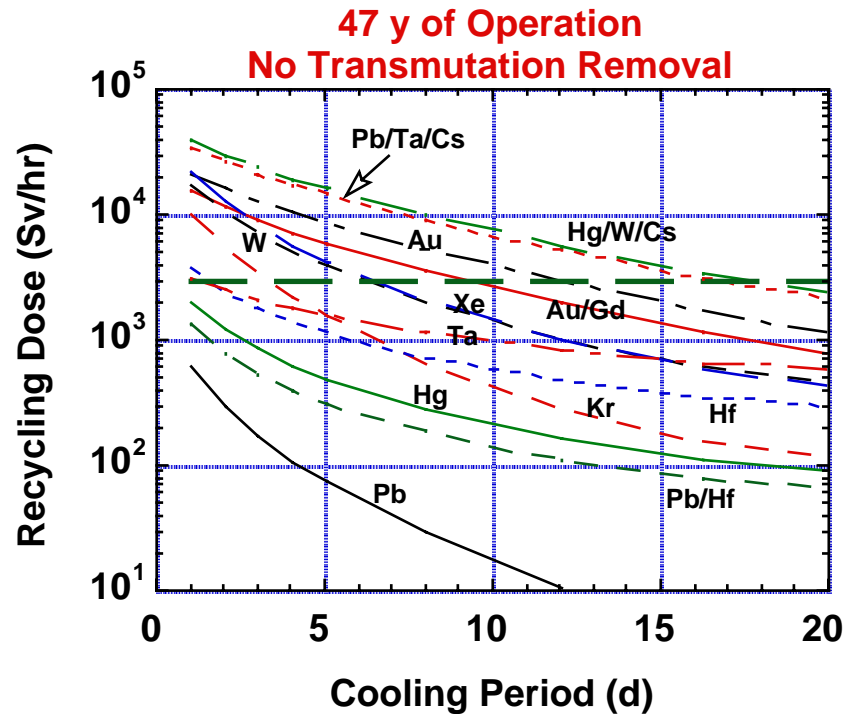
Same as Japanese and European limits

# Based on 20 mSv annual limit for 2000 h/y worker

## Based on arbitrary factor of 1000 above HO limit

+ For fission waste, per N. Taylor. On-going EU recycling study will develop RH limit for fusion waste

# Recycling Dose



- Only Pb can meet HO limit ( $1 \mu\text{Sv/h}$ ) with long cooling period ( $\sim 2$  y)
- All materials meet advanced RH limit ( $3000 \text{ Sv/h}$ ) with  $< 18$  d cooling period
- On-line removal of transmutation products shortens cooling period



# Recommended Cooling Period to Meet Both WDR and Dose Requirements<sup>#</sup>

	Cooling Period for <b>WDR</b> < 1	Cooling Period for <b>Dose</b> < 3000 Sv/h	<b>Recommended Cooling Period</b>
Au/Gd	> 2 y	9.5 d	NA*
Au	8.2 d	12.2 d	12.2 d
W	0	6.2 d	6.2 d
Pb	13 d	< 1 d	13 d
Hg	5 d	< 1 d	5 d
Ta	0	1 d	1 d
Pb/Ta/Cs	7.5 d	17.2 d	17.2 d
Hg/W/Cs	3 d	17.5 d	17.5 d
Pb/Hf	11.5 d	< 1 d	11.5 d
Hf	0.6 d	1.5 d	1.5 d
Solid Kr	250 d	4.5 d	250 d
Solid Xe	0	6.5 d	6.5 d

<sup>#</sup> 47 y of operation. No transmutation removal  
 \* Insignificant inventory reduction for cooling period exceeding 2 y.

On-line removal of transmutation products shortens cooling period further and may allow recycling of Gd





# Main Contributors to WDR and Dose

	<b>WDR*</b>	<b>Dose#</b>
<b>Au/Gd</b> (50:50)	$^{158}\text{Tb}$	$^{196}\text{Au}$
<b>Au</b>	$^{192}\text{nIr}, ^{194}\text{Hg}$	$^{196}\text{Au}$
<b>W</b>	$^{186}\text{mRe}, ^{178}\text{nHf}$	$^{184}\text{Re}$
<b>Pb</b>	$^{208}\text{Bi}, ^{202}\text{Pb}$	$^{203}\text{Pb}, ^{202}\text{Tl}$
<b>Hg</b>	$^{192}\text{nIr}, ^{194}\text{Hg}$	$^{202}\text{Tl}, ^{196}\text{Au}, ^{203}\text{Hg}$
<b>Ta</b>	$^{178}\text{nHf}$	$^{182}\text{Ta}, ^{179}\text{nHf}$
<b>Pb/Ta/Cs</b> (45:20:35)	$^{208}\text{Bi}, ^{202}\text{Pb}$	$^{132}\text{Cs}$
<b>Hg/W/Cs</b> (45:20:35)	$^{192}\text{nIr}, ^{194}\text{Hg}$	$^{132}\text{Cs}, ^{203}\text{Pb}, ^{202}\text{Tl}$
<b>Pb/Hf</b> (70:30)	$^{208}\text{Bi}, ^{202}\text{Pb}$	$^{175}\text{Hf}$
<b>Hf</b>	$^{178}\text{nHf}^{**}$	$^{175}\text{Hf}, ^{179}\text{nHf}^{**}, ^{179}\text{Lu}$
<b>Kr</b>	$^{81}\text{Kr}$ (gas)	$^{84}\text{Rb}, ^{82}\text{Br}$
<b>Xe</b>	$^{129}\text{I}, ^{135}\text{Cs}, ^{137}\text{Cs}$	$^{134}\text{Cs}, ^{132}\text{Cs}, ^{127}\text{Xe}$ (gas)

In some cases, same elements contribute to both WDR and dose

Efficient on-line clean-up system could remove almost all radioisotopes

\* 47 y of operation with no cooling period. No transmutation removal

# Contributors at recommended cooling period for dose. 47 y of operation. No transmutation removal

\*\* Difficult to separate



# Disposal of Radioactive Kr & Xe Gases (valid also for chamber buffer gases)

Filter out solid transmutation products using cold traps, per Sze (UCSD)

Use laser-based isotope separation system for gases and solids, per Waganer (Boeing) [Ref: Prometheus Report, DOE/ER-54101, P 6.7-8 (1992)]

Store gases in glass spheres, per Nikroo (GA):

- Heat up glass shells
- Fill out shells with gases
- Cool down to trap gases inside shells
- Store for future use or dispose in repositories

Store Kr in hydrides, per Malang (FZK):

- Heat up hydrides
- Allow Kr to permeate through hydrides
- Cool down hydrides
- Store for future use or dispose in repositories

# Conclusions

- Hohraum walls represent small waste stream for IFE (< 1% of total nuclear island waste)  $\Rightarrow$  recycling is not a must unless materials have cost/resources problems
- One-shot use of hohraum generates 43 m<sup>3</sup> of very low waste (Class A)
- Recycling introduces activation problems, adds complexity, and mandates remote handling (costly) in target Fab
- WDR and recycling dose are most restrictive factors in recycling process
- Three potential solutions could solve recycling problems: **efficient** transmutation removal system, limited exposure time, and controlled cooling period
- **Highly efficient** on-line clean-up system removes **most** transmutation products and allow recycling of **all** materials
- In absence of **efficient** system, exclude Gd for generating HLW after 10 pulses and use other materials with 2-8%<sup>#</sup> penalty in driver's cost and small hit in cost of electricity (< 5%<sup>#</sup>). Excessive Au/Gd unit cost may outweigh benefits
- **Attractive scheme would combine efficient clean-up system and controlled cooling period. Additional cost and complexity of recycling should be addresses.**
- Clean-up system will filter out cup(s) of **HLW that could be burned in special modules to avoid deep geological burial\*** and meet ARIES Class C-only waste requirement

# Does not include cost of hohraum wall materials

\* L. El-Guebaly, "Need for Special Burning Modules in Fusion Devices to Transmute Fusion High Level Waste", To be published in May 2002.

